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USER'S GUIDE

User's Guide: Asphalt Rubber Concrete Pavement

by

Gary L. Anderton
U.S. Army Engineer Waterways Experiment Station
Vicksburg, MS 39180-6199

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U.S. Army Center for Public Works
Alexandria, VA 22310-3860

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Asphalt rubber concrete pavements include at least two types of flexible pavement surfacings made with asphalt rubber cement as the binder; stone mastic and open-graded mixtures. The asphalt rubber binder generally contains 15-25 percent recycled scrap tire rubber blended with standard paving grade asphalt cement. Asphalt rubber concrete pavements are applicable to virtually any flexible pavement surfacing requirement, providing such performance benefits as reduced temperature susceptibility, reduced low-temperature cracking potential, reduced high temperature deformation distress potential, reduced age-hardening potential, and reduced binder-aggregate stripping potential.

This report includes discussions of the description, applications, benefits, limitations, costs, and recommended uses for asphalt rubber concrete pavements. A model guide specification for open and gap-graded asphalt rubber concrete pavements is also provided in the appendix of this report.

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Contents

1 Executive Summary

Description

Asphalt rubber concrete pavements include at least two types of flexible pavement surfacing often made with asphalt rubber cement as the binder; stone mastic and open-graded mixtures. (There is some disagreement in the industry concerning the definition of a stone mastic versus open or gap-graded mixtures. This report does not attempt to address that agreement but includes both descriptions for the reader's benefit.) The asphalt rubber binder generally contains 15-30 percent of finely ground up recycled scrap tire rubber blended with standard paving grade asphalt cement. The recycled rubber is ground to various particle sizes, preblended with the asphalt cement at elevated mixing temperatures, and then used in the same manner as standard asphalt cements are used in flexible pavement surface mixtures.

Applications

Asphalt rubber concrete pavements are applicable to virtually any flexible pavement surfacing requirement. Successful applications of asphalt rubber concrete pavement have been documented for airports, heavily-trafficked highways, and urban roads and streets.

Benefits

Asphalt rubber concrete pavements can provide several performance benefits over traditional asphalt concrete pavements, including: reduced temperature susceptibility, reduced low-temperature cracking potential, reduced high-temperature deformation distress potential, reduced age-hardening potential, and reduced binder-aggregate stripping potential. The increased viscosity of asphalt rubber binders make them particularly well-suited for stone mastic and open-graded paving mixtures.

Limitations

The use of asphalt rubber materials may be somewhat limited by local availability. It is expected that the number of asphalt rubber suppliers will increase and become more widespread in the coming years as this technology becomes more popular, however. The most notable limitation in using asphalt rubber currently is the determination of whether the projected cost savings from improved performance outweighs the higher initial costs of materials and construction.

Costs

Asphalt rubber concrete pavements can cost 50-150 percent more to produce and place when compared to standard asphalt concrete pavements. Life-cycle cost savings should be realized with asphalt rubber concrete, however, as certain applications will provide reduced maintenance costs and longer service lives. The projected life-cycle cost savings must exceed the increased cost of construction in order for the asphalt rubber alternative to be cost-effective.

Recommendations for Use

Asphalt rubber concrete pavement is recommended for use whenever local experience with standard asphalt concrete pavement indicates that the asphalt rubber alternative will provide performance and cost saving benefits that outweigh the higher initial cost associated with asphalt rubber. The asphalt rubber concrete alternative is generally suitable for any type of flexible pavement system. As this is an emerging technology, any recent local experiences and the latest design and construction guidance should be used when involved in an asphalt rubber concrete pavement project.

No guide specification for military construction currently exists for asphalt rubber concrete pavements. Guide specifications on this technology have been prepared by several other governmental transportation agencies and by private industry, however. One example of a guide specification for open and gap-graded asphalt rubber concrete pavements is found in Appendix A of this report. It is recommended that this guide specification be used as a model until such time that a Corps of Engineers Guide Specification (CEGS) is published or until a more suitable guide specification model is produced.

Points of Contact

Points of contact regarding this technology are:

Technical

Director
U.S. Army Waterways Experiment Station
ATTN: CEWES-GP-Q (Mr. Gary L. Anderton)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Telephone: 601-634-2955
Facsimile: 601-634-3020

FEAP Program Monitor

Commander
U.S. Army Center for Public Works
ATTN: CECPW-ER (Mr. Lloyd N. Werthmuller)
7701 Telegraph Road
Alexandria, VA 22310-3862
Telephone: 703-806-5997
Facsimile: 703-806-5219

2 Preacquisition

Description of Asphalt Rubber Binders

Asphalt rubber binders are produced by blending and reacting traditional asphalt cements with 15-25 percent ground reclaimed tire rubber at elevated mixing temperatures. Reaction of the rubber particles in the asphalt cement generally involves blending for an hour or more at temperatures in the 175-205 deg C range. This reaction time allows the rubber particles to swell, producing a binder with improved temperature susceptibility, flexibility and elasticity as compared to most unmodified asphalt cements. The antioxidants and carbon black in the tire rubber also act to reduce the natural aging process of the binder.

Higher than normal binder contents (2-5 percent higher) can be utilized with asphalt rubber binders because of their higher viscosities at typical asphalt concrete mix temperatures. The higher viscosities and higher binder contents result in thicker binder films on the aggregates, which in turn improves aging resistance and durability. Higher binder contents also provide greater flexibility in the pavement surfacing, increasing the pavement's resistance to fatigue cracking.

Applications

Asphalt rubber binders have been successfully used in the past in several pavement applications, including: pavement crack and joint sealants, stress absorbing membrane (SAM) surfacings, stress absorbing membrane interlayers (SAMI), and various types of hot mix asphalt (HMA) applications. In recent years, the development of the asphalt rubber HMA technologies has gained interest in the pavements community. The highly viscous nature of asphalt rubber binders make them particularly well-suited for gap-graded or "stone mastic" mixtures and open-graded mixtures. These two types of HMA surfacings are relatively new to U.S. practice. The asphalt rubber technologies; however, are applicable to virtually any flexible pavement system where increased durability and resistance to cracking and weathering are desired. Successful applications of asphalt rubber concrete pavement have been documented for airports, heavily-trafficked highways, and urban roads and streets.

Design Methods

Areas of design which must be addressed for both the stone mastic and open-graded asphalt rubber applications include those of the asphalt rubber binder, aggregates, asphalt rubber and aggregate mixture, and the pavement cross section or thickness design. Each of these design areas are addressed in the guide specification found in the appendix of this report. However, the asphalt rubber HMA area is a developing technology and the latest design guidance and experienced contractors should be sought out on each project. General design considerations not specifically addressed in the attached guide specification are discussed in the following paragraphs.

As with any pavement design, the selection of materials should be heavily influenced by local experiences. Since the rubber particles create a highly viscous binder, a good rule to follow when selecting the base asphalt cement is to use one grade lower (or less viscous) than the grade normally used in the particular area. The amount of rubber used in the binder will to a large extent determine the amount of the increased viscosity. Also, the chemical make-up of the asphalt cement will influence the degree of reaction that occurs and therefore the quality of the resulting binder. Asphalts which have higher degrees of aromaticity will dissolve and interact with the ground tire rubber to a much greater degree than asphalts with lower aromatic contents. Ground rubber particle size, shape and texture can also influence the physical characteristics of the resulting asphalt rubber binder. Use of local experience or the experiences of similar projects from similar environments will aid in the selection of the proper asphalt rubber material.

There should be no significant difference in the required aggregate properties when using asphalt rubber binders in either the stone mastic or open-graded asphalt mixtures. It is possible to decrease the amount of fine aggregates required in both types of HMA applications as the increased binder contents and viscosities will fill some of the void spaces created by the lack of fine aggregates without substantial loss in stability. The recommended aggregate gradations for both types of HMA applications are given in the guide specification found in the appendix of this report.

There are two areas of mix design that will be different when using asphalt rubber binders in stone mastic or open-graded asphalt mixtures. The first area of significant difference is the increased binder content allowed by the asphalt rubber's higher viscosity. Binder content increases of 2-5 percent may be physically possible without negative effects, but the increased binder content for asphalt rubber mixtures will generally be limited by the desired pavement improvements and costs. As a minimum, the binder content should be increased for an asphalt rubber mixture by an amount equal to the amount of rubber in the binder. The second area of mix design requiring a significant change for asphalt rubber mixtures is the mix temperature. Because of the increased viscosities of asphalt rubber binders, mix temperatures are usually increased 15-40 deg C. The particular viscosity characteristics of the asphalt rubber binder used will determine the mix design temperature. These two issues as well as others relating to asphalt rubber concrete mix design are addressed in the attached guide specification.

Thickness designs are, for the most part, unchanged for asphalt rubber concrete mixtures. Open-graded asphalt surfacings are generally only 3/4- to 1-in.-thick when unmodified binders are used and there is no current evidence to warrant any change in thickness for asphalt rubber open-graded surfacings. At least two states, Arizona and California, have successfully constructed asphalt rubber dense-graded roadway surfacings at one-half of the design thickness for an unmodified dense-graded surfacing[1]. Therefore, although the stone mastic aggregate grading is quite different from the traditional dense-graded system, it could be possible to reduce the SMA thickness when asphalt rubber binders are used. This concept of reduced thickness with equal performance for asphalt rubber stone mastic surfacings must be proven in field trials before a full-scale application is attempted, however.

Construction Techniques

Construction of an asphalt rubber concrete pavement requires a few changes from the techniques used with unmodified asphalt concrete mixtures. The first of these modifications is at the asphalt plant where the asphalt rubber concrete mixture is produced. Most asphalt rubber binders will require a separate binder storage tank with appropriate agitation to prevent segregation of the ground tire rubber and asphalt cement. This storage tank must be able to evenly heat the binder at elevated temperatures, generally 150-190 deg C. In addition to this storage tank, a separate supply system equipped with a pump and metering device capable of combining the viscous asphalt rubber binder with the aggregates at the correct percentage should be used.

The most notable difference between asphalt rubber concrete mixtures and unmodified asphalt concrete mixtures during placement is the mix temperature. Asphalt rubber concrete mixtures are required to be at least 15 deg C higher than unmodified mixtures and can be up to 40 deg C higher if needed. The increased mix temperature allows asphalt rubber concrete mixtures to be hauled, placed, and compacted in much the same manner as unmodified mixtures. Because the asphalt rubber mixtures tend to be somewhat sticky when hot, rubber tire rollers will usually pick up the mix during compaction and therefore are not used to compact asphalt rubber concrete mixtures. Rubber tire rollers are generally not used on open-graded and stone mastic mixes regardless of the binder type, so their exclusion from these mixture types with asphalt rubber binders should not be an issue.

Quality control testing of asphalt rubber concrete mixtures is also slightly modified to account for the different binder. Current methods of binder extraction using solvents are not effective in determining binder content. It is possible through standard extraction techniques, however, to clean the aggregates in an asphalt rubber concrete sample to a point where a suitable sieve analysis can be conducted. Nuclear gauges designed to determine binder contents are currently the most effective method of determining asphalt rubber binder contents in field samples.

Limitations/Disadvantages

The use of asphalt rubber binders in either an open-graded or stone mastic mixture may be somewhat limited by local availability of the binder. It is expected that the number of reclaimed rubber and asphalt rubber suppliers will increase and become more widespread in the coming years as this technology becomes more popular, however. Also, new techniques involving central plant production of more stable blends should make these binders easily accessible to virtually any asphalt concrete plant location in the near future. The number of paving contractors experienced in constructing asphalt rubber concrete pavements is another limitation that should be lessened as the asphalt rubber industry continues to grow.

The most notable limitation in using asphalt rubber binders currently is the initial or "first" cost. Current cost comparisons indicate that asphalt rubber concrete pavements can cost 50-150 percent more to produce and place when compared to unmodified asphalt concrete pavements[2]. Therefore, the projected cost savings from improved performance (longer pavement life and/or less maintenance) must outweigh the higher initial construction costs in order for the asphalt rubber alternative to make economic sense. Further information on the cost issue is provided in the following section of this chapter.

Life Cycle Costs

Asphalt rubber binders typically cost from two to four times as much as unmodified asphalt cement[2]. This binder cost increase can result in a 50-150 percent increase in the cost of an open-graded or stone mastic pavement surfacing. Even with this considerable increase in initial cost, there are numerous considerations that could make an asphalt rubber concrete pavement less expensive than an unmodified asphalt concrete pavement in terms of life cycle costs and possibly even in initial cost. These considerations, which have already been proven in many field applications[1], include: reduced thickness with equal or better performance, allowance of a less expensive overlay design versus a reconstruction design, and reduced maintenance costs. Each of these considerations along with any others that effect life cycle costs will have to be considered when making economic comparisons between asphalt rubber and unmodified asphalt concrete mixtures.

In attempting to project the future of asphalt rubber prices, it is helpful to note the bid experiences of the state of Arizona, perhaps the most experienced state in terms of asphalt rubber usage. During the last ten years in Arizona, the average low bid price for asphalt rubber cement has fallen from 505 $/ton to 263 $/ton[2]. During this same time frame, the national average cost of asphalt cement has fallen from the 150-175 $/ton range to approximately 125 $/ton. If this trend continues, the initial cost difference between AR concrete pavements and unmodified AC pavements will become even smaller.

Advantages/Benefits

Asphalt rubber binders can provide a number of advantages over unmodified asphalt cements when used in open-graded or stone mastic asphalt concrete pavement surfacings. Some of these benefits are due to the unique physical and chemical characteristics of the asphalt rubber binder while others are due to the fact that more binder is allowable in the mixture when using asphalt rubber. The most significant of the asphalt rubber advantages are discussed in the following paragraphs.

Undoubtedly, the most important benefit of a properly functioning open-graded asphalt concrete surfacing relates to enhanced vehicle/passenger safety. When substituting an open-graded surfacing for a typical dense-graded asphalt concrete surfacing, safety is improved by reducing water spray from passing traffic, thus improving visibility, and reducing hydroplaning by preventing accumulation of surface water. Dry weather skid resistance is also improved by the roughened surface texture of the open-graded asphalt concrete surfacing.

Open-graded asphalt pavements have a tendency towards premature failures due to the lack of fine aggregates in the mixture and the intentionally designed high void contents. The use of asphalt rubber binders in open-graded mixtures can solve many of the durability problems associated with unmodified open-graded asphalt concrete. The use of asphalt rubber permits higher binder contents, thus thicker binder films (due to the high viscosity of the asphalt rubber) without excessive drain-off. The increased binder film helps to increase the mixture's high-temperature stability, reduce reflective cracking, and resist stripping in the presence of water. The antioxidant materials found in the tire rubber teamed with the thicker binder films also helps to reduce the negative effects of oxidation or "age hardening"[3]. A possible site specific benefit of using asphalt rubber in open-graded pavement surfacings is that the asphalt rubber mixtures can be placed in colder than normal ambient temperature conditions due to the allowable higher mix temperatures.

The benefits provided by a stone mastic asphalt (SMA) pavement when compared to a typical dense-graded asphalt pavement lie in the designed stone-to-stone contacts or "aggregate interlock" and the higher allowable binder contents. This unique combination helps to provide a more durable and flexible asphalt concrete pavement with increased resistance to reflective cracking, rutting and oxidation. The advantage of using an asphalt rubber binder in a SMA mixture is simply tied to the increased binder viscosity during mixing, placing, and under traffic at high service temperatures. With unmodified asphalt cements, a certain amount of mineral filler is usually required to stiffen the binder and to prevent bleeding from higher than normal binder contents. This mineral filler may not be required in asphalt rubber SMA mixtures to obtain equal or superior performance. SMA mixtures by nature require a more viscous binder, either mechanically or chemically induced, and asphalt rubber binders are well-suited for these types of asphalt concrete mixtures.

3 Acquisition/Procurement

Potential Funding Sources

Typically, installations fund the implementation of pavements and railroads technologies from their annual budgets. However, the installation's annual budget is usually underfunded and the pavements and railroads projects do not compete well with other high visibility or high interest type projects. As a result, it is prudent to seek out additional funding sources when the project merits the action. Listed below are some sources commonly pursued to fund projects.

a. *Productivity program.* See AR 5-4, Department of the Army Productivity Improvement Program for guidance to determine if the project qualifies for this type of funding.

b. *Facilities Engineering Applications Program (FEAP).* In the past, a number of pavement and railroad maintenance projects located at various installations were funded with FEAP demonstration funds. At that time, emphasis was placed on demonstrating new technologies to the Directorate of Engineering and Housing (DEH) community. Now that these technologies have been demonstrated, the installations will be responsible for funding their projects through other sources. However, emphasis concerning the direction of FEAP may change in the future; therefore, one should not rule out FEAP as a source of funding.

c. *Special programs.* Examples of these are as follows:

   (1) FORSCOM mobilization plan which may include rehabilitation or enlargement of parking areas and the reinforcement of bridges.

   (2) Safety program which may include the repair of unsafe/deteriorated railroads at crossings and in ammunition storage areas.

   (3) Security upgrade which may include the repair or enlargement of fencing.

d. *Reimbursable customer*. Examples of this source are roads to special function areas such as family housing or schools and airfield pavements required to support logistical operations.

e. *Special requests from MACOMS*.

f. *Year end funds*. This type of funding should be coordinated with the MACOMs to ensure that the funds will not be lost after a contract is advertised.

g. *Operations and Maintenance Army*. These are the normal funds used for funding pavement and railroad projects.

Technology Components and Sources

Components of the technology which must be procured for the use of asphalt rubber concrete pavement are: section design (may be in-house or contracted out) and a construction contract for the asphalt rubber concrete pavement. Additional requirements of an asphalt rubber concrete mixture plant when compared to traditional asphalt concrete plants include the following: a separate binder storage tank with agitation capabilities (mechanical stirring or pumped circulation) to keep the asphalt cement and rubber particles from separating; an evenly distributed heating source for the asphalt rubber storage tank; and a separate binder supply system equipped with a pump and metering device capable of combining the viscous asphalt rubber binder with the heated aggregates at the correct percentage.

Asphalt rubber suppliers and paving contractors experienced with asphalt rubber concrete pavements are available in virtually all areas of the United States. The most current design and construction guidance should be sought out and used on every asphalt rubber concrete pavement project. These types of guidance documents are currently being produced by a number of agencies, including the Federal Highway Administration (FHWA), most state Departments of Transportation (DOT), and numerous independent asphalt rubber suppliers, contractors, and engineering consultants. Technical guidance and further information on asphalt rubber concrete pavement market in the United States may be obtained by contacting:

Rubber Pavements Association
312 Massachusetts Avenue, NE
Washington, DC 20002
Telephone: 202-544-7111
Facsimile: 202-544-7146

Procurement Documents

Technical reports

The Corps of Engineers has published two technical reports on research studies of asphalt rubber concrete pavements:

"Evaluation of Asphalt Rubber Binders in Porous Friction Course," Technical Report CPAR-GL-92-1, USAE Waterways Experiment Station, 1992.

"Summary of Research on Asphalt Rubber Binders and Mixes," Technical Report CPAR-GL-92-2, USAE Waterways Experiment Station, 1992.

Applicable specifications

No current Corps of Engineers Guide Specification exist on asphalt rubber concrete pavements. There are, however, guide specifications used within the construction industry, including the one found in Appendix B of this report.

GSA listing

None

Vendors list and recent prices

Any local contractor with experience in asphalt paving should be able to successfully construct an asphalt rubber concrete pavement. As this is a relatively new paving technology with mostly test sections and pilot projects constructed, recent prices are highly variable and would not reflect a current pricing standard.

Procurement Scheduling

Normal construction contract schedules should be established that allow adequate design and plan preparation time, design and review approval, contract preparation, advertising and award, and construction time. A typical pavement project is designed 1-2 years before it is constructed; however, relatively small projects that require limited plans and specifications can be prepared and ready to go within a few months.

4 Post Acquisition

Initial Implementation

Equipment

Conventional asphalt concrete mixing and asphalt concrete paving equipment can be used to produce, place, and compact asphalt rubber concrete pavements. However, early test sections and pilot projects have indicated some slight changes to normal procedures required by asphalt rubber concrete mixtures. A separate asphalt rubber storage tank with sufficient agitation capabilities is required to keep the asphalt cement and rubber particles from separating during storage. This storage vessel must be equipped to evenly heat the asphalt rubber binder to mix temperatures ranging from 150-190 deg C. The asphalt rubber cement itself will require larger than normal pumps and pump lines at the asphalt plant to handle the increased viscosity of the binder. Mixing, lay down, and compaction temperatures are also usually higher than normal to account for the increased stiffness of the hot asphalt rubber mixture. Rubber tire rollers are not suitable for asphalt rubber mixtures as the increased adhesion of the binder may cause the mix to adhere to the rubber tires during compaction.

Materials

The materials used to produce asphalt rubber concrete mixtures are basically the same as those used to produce unmodified asphalt concrete mixtures except for the binder. The aggregate gradations and physical requirements, as detailed in Appendix B of this report, are particularly important for open-graded and stone mastic pavement mixtures to ensure strength and stability from the designed stone to stone contacts. An additional aggregate material required only for asphalt rubber concrete pavements in some circumstances is called a "blotter material." Blotter material may be a fine aggregate or sand (meeting the gradation requirements detailed in the attached specification), and is used to prevent the freshly placed mix from picking up during construction or from early trafficking.

The asphalt rubber binder is a combination of two materials, traditional asphalt cement and reclaimed crumb rubber, with the possibility of an extender oil added when needed to reduce viscosity. All three of these materials are detailed in the attached specification. As the asphalt rubber technology continues to develop, slight modifications to these specification requirements may be required.

Personnel

The personnel normally required at an asphalt mixture production plant and those required for asphalt concrete construction are the same as those needed for the production and construction of an asphalt rubber concrete pavement. The same similarities exist when comparing the required quality control personnel of both types of pavement construction. The only possible exception may be when a unique asphalt rubber mixing and storage tank is mobilized at the production plant. In this case, the asphalt rubber binder supplier may require one or two trained personnel to operate or supervise the operation of the binder vessel and pumping system.

Procedure

The general procedures used to construct an asphalt rubber concrete pavement are basically the same as those used to construct an unmodified asphalt concrete pavement. As previously discussed, only slight modifications at the asphalt mix plant and during placement are required when using asphalt rubber binders. Typical construction procedures are also presented in the attached guide specification.

Operation and Maintenance

Operation and maintenance of asphalt rubber concrete pavements are no different than with unmodified asphalt concrete pavements. The stone mastic asphalt pavement surfacing generally performs in the same manner as a traditional dense-graded asphalt concrete surfacing. An open-graded surfacing may require special maintenance considerations, however. Open-graded surfacings require a sound foundation and a good quality intermediate course of asphalt concrete (free of cracks) since the open-graded material will not resist reflective cracking. If some minor reflective cracking occurs in the open-graded surfacing, the cracks must be properly sealed as soon as possible to prevent edge raveling along the crack facings. Crack sealing will usually interrupt water drainage flow in the crack area, but must be done to prevent further deterioration of the open-graded surfacing. Open-graded surfacings also require rubber tipped blades on any snow removal equipment to prevent possible surface raveling from scraping plow blades.

Service and Support Requirements

No special services or support are required to implement or maintain this technology.

Performance Monitoring

Installation personnel can monitor and measure the performance of an asphalt rubber concrete pavement by making periodic inspections of the pavement for signs of distress (cracking, rutting, flushing, etc.). This monitoring of performance would be no more than that required for any asphalt concrete pavement. The performance monitoring can be adjusted to fit into existing pavement management systems.

References

Anderton, G. A. (1992). "Evaluation of Asphalt Rubber Binders in Porous Friction Courses," Interim Report CPAR-GL-92-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Forstie, D. A. and Way, G. B. (1994). "ADOT's Use of Crumb Rubber in Asphalt Pavements," Arizona Department of Transportation, Phoenix, AZ.

Morris, G. R. (1993). "True Cost Effectiveness of Asphalt Rubber Paving Systems," Standard Technical Publication 1193, American Society for Testing and Materials, pp 293-302, Philadelphia, PA.

Appendix A
Fact Sheet

MATERIAL: Asphalt Rubber

DESCRIPTION:

Asphalt rubber is a modified bituminous material made by reacting 15-30 percent reclaimed rubber with asphalt cement at elevated mixing temperatures (175-205°C). The rubber may be reclaimed from buffings wasted during the tire manufacturing process or from ground up whole waste tires. Asphalt rubber technologies are marketed by the Rubber Pavements Association in Washington, DC.

AREAS OF APPLICATION (AS RECOMMENDED BY PRODUCERS):

1. High viscosity binder in open-graded or gap-graded hot mix asphalt.

2. Binder materials in pavement stress-absorbing membranes (SAM) or stress-absorbing membrane interlayers (SAMI).

3. Pavement spray applications and surface treatments.

4. Pavement joint and crack sealer material.

5. Waterproofing liners on expansive soils, man-made ponds, mining leaching pads, bridge deck membranes, and land fills.

PHYSIOGRAPHIC FACTORS:

Asphalt rubber binder materials are generally delivered to the job site pre-blended. Heating temperatures before application are somewhat higher than for unmodified asphalt cements because of the asphalt rubber binder's increased viscosity. The higher viscosity at application temperatures may also require separate storage vessels, larger capacity pumps, and larger feed lines.

DISCUSSION AND RECOMMENDATIONS:

Developed in the late 1960's, asphalt rubber binders have been used throughout the United States and other countries to improve the performance of asphalt concrete pavements. Recent advances in asphalt rubber technology coupled with the growing environmental concerns of waste tire stockpiles have prompted many state and federal agencies to fully implement asphalt rubber technology in their pavement systems. Full-scale trials on city streets, highways, and airport pavements have been documented all over the United States. These field applications, along with numerous recent research studies, indicate that asphalt rubber binders can provide the following benefits:

* reduced temperature susceptibility

* reduced low-temperature cracking

* reduced high-temperature deformation distresses

* reduced age hardening

* reduced binder-aggregate stripping

* more durable, longer lasting friction courses

Asphalt rubber binders have a well-established history in spray applications, surface treatments, SAM's and SAMI's, joint and crack sealants, and as a waterproofing liner. The technologies surrounding this binder's use in hot mix asphalt applications continues to be developed. Asphalt rubber should be considered as a binder in hot mix asphalt applications whenever any of the potential benefits listed above are desired. The pavement designer will have to consider an applicable reduced pavement thickness due to increased strength properties, which should counteract the increased cost (50-150%) to produced an asphalt rubber concrete mixture.

<u>SUMMARY:</u>

Based on field trials in the last 20 years and recent research studies, asphalt rubber binders are considered to be a viable binder alternative when increased pavement performance is desired. Asphalt rubber binders should be considered as the optimum binder material in certain applications of SAM's, SAMI's, surface treatments, joint and crack sealants, and waterproofing liners. The increased viscosity and higher cost of asphalt rubber binders must be considered during design and construction.

Appendix B
Guide Specification

GUIDE SPECIFICATION

FOR

OPEN AND GAP-GRADED ASPHALT-RUBBER CONCRETE PAVEMENTS

1. SCOPE

This specification covers material, equipment, and construction procedures for ______[A] asphalt-rubber concrete pavement using a reacted asphalt-rubber binder.

2. PREQUALIFICATION OF A NEW ASPHALT-RUBBER MATERIAL

Prequalification of a new asphalt-rubber material or applicator/supplier may be requested at any time. Prequalification will be based on three controlled field applications evaluated after three years' performance under traffic. The controlled field applications may be of other construction related uses utilizing asphalt-rubber materials. New asphalt-rubber material that has been evaluated and prequalified by an agency recognized nationally may be prequalified by that agency upon disclosure of suitable evidence of successful performance. Notwithstanding other agency prequalification, this agency reserves the right to withhold prequalification pending the performance evaluation of local controlled field applications.

3. ASPHALT-RUBBER BINDER

3.1 GENERAL: The asphalt-rubber binder shall be a uniform reacted blend of compatible paving grade asphalt cement, crumb rubber modifier (CRM), and other additives, if required. The asphalt-rubber binder shall be ____[B] climate type binder and shall meet the physical parameters listed in Table 1 for the type of binder specified

Note: Attached are "Notes to Engineer" which are referenced by a superscript letter (i.e. [z]). It is important to refer to these notes when developing a specification from this guide for highway, road, street, and airport asphalt-rubber paving projects.

Please be advised that these are only general recommendations, not rigid specifications. For additional information contact:

International Surfacing Inc.
6751 W. Galveston
Chandler, AZ 85226

Attn.: Mr. Joe Cano, P.E., Technical Director
(602)268-0874

February 17, 1994

TABLE 1: SPECIFICATIONS FOR ASPHALT-RUBBER BINDER

CLIMATE TYPE		Hot (a)	Moderate (b)	Cold (c)
Apparent Viscosity, 350°F Spindle 3, 20 RPM, cP, (ASTM D 2196)[1]	Min Max	1,500 5,000	1,500 5,000	1,500 5,000
Penetration, 77°F, 100g, 5 sec.: 1/10 mm. (ASTM D 5)	Min Max	25 75	25 75	50 100
Penetration, 39.2°F, 200g, 60 sec.: 1/10 mm. (ASTM D 5)	Min	10	15	25
Softening Point: °F: (ASTM D 36)	Min	135	130	125
Resilience, 77°F:%: (ASTM D 3407)	Min	25	20	15
TFOT Residue, (ASTM D 1754) Penetration Retention, 39.2°F: %	Min	75	75	75

a. Hot Climate - Average monthly maximum 110°F or greater
Average monthly minimum 30°F or greater

b. Moderate Climate - Average monthly maximum 110°F or lower
Average monthly minimum 15°F or greater

c. Cold Climate - Average monthly maximum 80°F or lower
Average monthly minimum 15°F or lower

[1] Either digital or dial reading viscometers may be used - record peak measurement.
For LV series models, use spindle 3 at 12 rpm
For RV and HA series models, use spindle 3 at 20 rpm.
Haake-type viscometers may be substituted, particularly for field control.

3.2 MATERIALS

.1 **Asphalt Cement:** The asphalt cement for the asphalt-rubber binder shall comply with requirements of ASTM D 3381 and AASHTO M 226. The grade selected shall be determined by laboratory testing performed by the asphalt-rubber supplier to ensure appropriate compatibility and reacting characteristics.[c]

.2 **Asphalt Extender Oil:** An asphalt extender oil may be added, if necessary, to meet the requirements of Table 1. Extender oil shall be a resinous, high flash point, aromatic hydrocarbon meeting the following test requirements:

Viscosity, SUS, at 100°F (ASTM D 88)	2500 minimum
Flash Point, COC, °F (ASTM D 92)	390 minimum
Molecular Analysis (ASTM D 2007):	
Asphaltenes, Wt. %	0.1 maximum
Aromatics, Wt. %	55.0 minimum

.3 Crumb Rubber Modifier (CRM)

.1 **General:** The crumb rubber modifier (CRM) shall be produced primarily from processing automobile and/or truck tires by ambient grinding methods. The CRM shall be substantially free from contaminants including fabric, metal, mineral, and other non-rubber substances. The CRM shall be sufficiently dry to be free flowing and not produce a foaming problem when added to hot asphalt cement. Up to 4% by weight of talc or other appropriate blocking agent can be added to reduce agglomeration of the rubber particles.

.2 Physical Requirements

.1 Gradation and Particle Length: When tested in accordance with ASTM C 136 using a minimum 5(gram sample, the resulting CRM gradation shall meet the following gradation limits for the CRN specified. CRM from more than one source may be used provided the combined rubber gradatior meets the specified limits.

TABLE 2: CRUMB RUBBER MODIFIER (CRM) GRADATION LIMITS

	Percent Passing	
Sieve Size	Type I	Type II
No. 8	100	—
No. 10	95 - 100	100
No. 16	40 -60	70 - 100
No. 30	0 - 20	25 - 60
No. 50	0 - 10	0 - 20
No. 200	—	0 - 5
Max. Particle Length	3/16"	3/16"

.2 Fiber Content: The CRM shall be designated Grade A or Grade B. For Grade A CRM, the fibe: content shall be less than 0.1% by weight. For Grade B CRM, the fiber content shall be less thar 0.5% by weight. Fiber content shall be determined by weighing fiber agglomerations which are formed during the gradation test procedure. Rubber particles shall be removed from the fibs agglomerations before weighing.°

.3 Moisture Content: For each CRM type and grade, the moisture content shall be less than 0.75% by weight.

.4 Mineral Contaminants: For each CRM type and grade, the mineral contaminant amount shall no be greater than 0.25% by weight as determined after water separating a 50 gram (minimum) rubbe sample in a 1 liter glass beaker filled with water.

.5 Metal Contaminants: The CRM shall contain no visible metal particles as indicated by thorougt stirring of a 50 gram (minimum) sample with a magnet.

.3 Packaging: The CRM shall be supplied in either: reusable bulk containers holding a minimum of 50C pounds of CRM; or in moisture resistant disposable bags with either 50 ± 2 pounds or 60 ± 2 pounds o CRM.

The weight of the CRM in the bulk containers shall be within 1.0 percent of the certified weight. The containers shall not be stacked on top of each other during storage or shipment.

The small bags (50 to 60 lbs.) shall be palletized into units, each containing 50 bags, to provide net palle weights of either 2,500 ± 100 lbs. or 3,000 ± 100 lbs. Glue shall be placed between layers of bags tc increase the unit stability during shipment. Palletized units shall be double wrapped with U. V. resistan stretch wrap.

.4 Labeling: Each container of CRM shall be labeled with the manufacturer's designation for the CRM, the specific type and grade of CRM in accordance with this specification (example - Type I, Grade A), the nominal CRM weight, and manufacturer lot number designation. Palletized units shall contain a labe which indicates the manufacturer designation, CRM type and grade, net pallet weight, and production lo number. The bulk containers (500+ lbs.) shall have the certified weight of CRM clearly marked on a least one side.

.5 Certification: The manufacturer shall ship along with the CRM, certificates of compliance which certify that each production lot number or shipment complies with all requirements of this specification.

3.3 ASPHALT-RUBBER BINDER DESIGN: The binder design shall be performed by the asphalt-rubber supplier. The proportion of CRM shall be between 15 and 23 percent by total weight of the asphalt-rubber binder mixture.

The asphalt-rubber supplier shall supply to the Engineer for approval a binder formulation at least 10 days before pavement construction is scheduled to begin. The binder formulation shall consist of the following information:

Asphalt Cement
Source and Grade of Asphalt Cement
Source and Grade of Additives Used
Percentage of Asphalt Cement and Additives by Total Weight of the Asphalt-Rubber Binder

Crumb Rubber Modifier (CRM)
Source and Grade of CRM
Percentage of CRM by Total Weight of the Asphalt-Rubber Binder

If CRM from more than one source is utilized, the above information will be required for each CRM used.

Specific Gravity of Aspalt-Rubber binder at 60 °F.

Physical properties of the blend in accordance with Table 1.

3.4 ASPHALT-RUBBER MIXING AND PRODUCTION EQUIPMENT: All equipment used in production and proportioning of the asphalt-rubber binder shall be described as follows:

.1 Asphalt Heating Tank: An asphalt heating tank with a hot oil heat transfer system or retort heating system capable of heating asphalt cement to the necessary temperature for blending with the CRM. This unit shall be capable of heating a minimum of 2,500 gallons of asphalt cement.

.2 Blender: The asphalt-rubber mechanical blender shall have a two stage continuous mixing process capable of producing a homogeneous mixture of asphalt cement and CRM, at the mix design specified ratios, as determined by the Engineer. This unit shall be equipped with a CRM feed system capable of supplying the asphalt cement feed system, as not to interrupt the continuity of the blending process. The maximum capacity of the primary blending vessel shall be 500 gallons. Both the primary and secondary blenders shall be equipped with an agitation device oriented horizontally in the blending vessel. The blending unit shall be capable of fully blending the individual CRM particles with the asphalt cement. A separate asphalt cement feed pump and finished product pump are required. This unit shall have both an asphalt cement totalizing meter in gallons and a flow rate meter in gallons per minute.

.3 Storage/Reaction Tank: An asphalt-rubber storage/reaction tank equipped with a heating system to maintain a temperature of 300°F to 375°F for reacting, pumping and adding the binder to the aggregate. The storage/reaction tank shall be separate from the primary and secondary blender of the blending unit. The maximum capacity of the storage/reaction tank shall be 8,000 gallons. This unit shall have an internal mixing unit capable of maintaining a uniform mixture of asphalt cement and CRM. The internal mixing device shall be oriented horizontally in the tank.

.4 Supply System: An asphalt-rubber supply system equipped with a pump and a direct interlock metering device capable of adding the binder by volume to the aggregate at the percentage required by the job-mix formula.

.5 Temperature Gauge: An armored thermometer of adequate range in temperature reading shall be fixed in the asphalt-rubber feed line at a suitable location near the mixing unit.

3.5 ASPHALT-RUBBER MIXING AND REACTION PROCEDURE

.1 **Asphalt Cement Temperature:** The temperature of the asphalt cement shall be between 375°F and 450°F at the addition of the CRM.

.2 **Blending and Reacting:** The asphalt and CRM shall be combined and mixed together in a blender unit, pumped into the agitated storage/reaction tank, and then reacted for minimum of 30 minutes from the time all the CRM is added to the asphalt cement. The quantity of CRM added shall be determined by weight for each batch. Temperature of the asphalt-rubber mixture shall be maintained at not less than 325°F during the reaction period. The asphalt-rubber may be allowed to cool to between 300°F and 350°F after it has reacted for the specified period.

.3 **Transfer:** After the material has reacted for at least 30 minutes, the asphalt-rubber shall be metered into the mixing chamber of the asphalt concrete production plant at the percentage required by the job-mix formula.

.4 **Delays:** When a delay occurs in binder use after its full reaction, the asphalt-rubber shall be allowed to cool. The asphalt-rubber shall be reheated slowly just prior to use to a temperature between 300°F and 375°F, and shall also be thoroughly mixed before pumping and metering into the hot plant for combination with the aggregate. The viscosity of the asphalt-rubber shall be checked by the asphalt-rubber supplier. If the viscosity is out of the range specified in Table 1 of this specification, the asphalt-rubber blend shall be adjusted by the addition of asphalt cement and/or CRM as required to provide the appropriate viscosity.

4. ASPHALT-RUBBER CONCRETE

4.1 MINERAL AGGREGATE

.1 **General:** The aggregate for the asphalt-rubber concrete mixture shall be composed of hard durable particles of crushed stone, crushed gravel, crushed slag, or expanded clay lightweight aggregate. The aggregate shall be free from clay balls or lumps, organic or decomposed materials, soft particles, adhered dust and deleterious coatings. Natural sand or manufactured sand may be used as the fine aggregate portion. Mineral filler, if used, shall meet the requirements of ASTM D 242 or AASHTO M 17.

.2 Physical Requirements[E]

.1 **Gradation:** The gradation of the aggregate shall meet the following limits when tested in accordance with ASTM C 136 or AASHTO T 11 and T 27.

Sieve Size	Percent Passing [E]
1"	
3/4"	
1/2"	
3/8"	
#4	
#8	
#30	
#200	

.2 **Fractured Faces:** The aggregate retained on the No. 8 screen shall consist of at least______[E] particles which have at least one fractured or crushed face.

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.3 Abrasion Loss: The aggregate shall have an abrasion loss which does not exceed______[c] when tested at 100 revolutions nor exceed______[c] when tested at 500 revolutions in accordance with ASTM C 131 or AASHTO T 96.

.4 Sand Equivalent Value: The sand equivalent value of the aggregate shall be a minimum of_______[c] when tested in accordance with ASTM D 2419 or AASHTO T 176.

4.2 ANTI-STRIPPING AGENT: If required by the Job-Mix Formula to produce appropriate water resistance, hydrated lime, Type II portland cement, or an anti-stripping agent that is heat stable and approved for use by the specifying agency shall be incorporated at the percentage required by the job mix formula.

4.3 BLOTTER REQUIREMENTS: Blotter material, if required, shall be composed of fine aggregate or dry washed sand meeting the following gradation requirements when tested in accordance with ASTM C 136 or AASHTO T 11 and T 27.

Sieve Size	Percent Passing
3/8"	100
No. 4	75 - 100
No. 16	45 - 80
No. 50	10 - 30
No. 100	0 - 10

5. JOB-MIX FORMULA

5.1 MIXTURE DESIGN: The mixture design shall be performed by the __________[c], and shall be used as the basis for determining the job-mix formula. The design method used shall be in accordance with ____________[c]. The mixture design shall be submitted to the Engineer at least 10 days prior to construction. Based on information contained in the mixture design, the Engineer shall approve a job-mix formula with the following tolerances allowed for single tests on aggregate gradation and asphalt-rubber binder content.

JOB MIX TOLERANCE

Sieve Size	Percent Tolerance
3/8" and larger	± 7
No. 4, No. 8, No. 30	± 5
No. 200	± 2
Asphalt-Rubber Binder Content	± 0.5

The mixture design shall include sufficient test results and documentation to assure that all requirements for the aggregate (Section 4) and the asphalt-rubber binder (Section 3) are fulfilled.

5.2 JOB-MIX FORMULA: The mixture design shall recommend the job-mix formula and shall list the followir information:

1. Aggregate
   - source and identification (for each material used)
   - gradation (for each material used)
   - blend percentage
   - mixture gradation

2. Asphalt-Rubber Binder
   - source, grade and percent of asphalt cement
   - source, grade and percent of CRM
   - type, source and percent of additive(s), if required

3. Anti-Strip Agent
   - Source of Anti-Strip
   - Percentage of Anti-Strip
     By Weight of the Asphalt Cement for liquid antistrip
     By Weight of Aggregate for lime or portland cement

4. Recommended asphalt-rubber binder content both by weight of total mix and by weight of dr aggregate.

5. Recommended mixture production temperature.

6. Recommended lay down temperature.

7. Density guidelines.

6. CONSTRUCTION EQUIPMENT

6.1 ASPHALT-RUBBER/AGGREGATE MIXING EQUIPMENT: The addition and mixing of the asphalt-rubber with the aggregate shall be accomplished with one of the following types of hot-mix asphalt plants.

Batch Mixing - Batch mix plant consisting of cold aggregate storage and feed, drier, gradation control unit hot aggregate storage bins, aggregate weigh-hopper, and a twin-shaft pugmill mixing unit. Also, the plant may be equipped with hot-mix surge or storage bins for short-term holding of the mixture until spreading.

Drier-Drum Mixing - Drier-drum mix plant consisting of cold aggregate storage and feed, automatic weighing system, drier-drum mixer and hot-mix surge or storage bins for short term holding of the mixture until spreading.

The asphalt-rubber/aggregate mixing equipment shall be capable of producing a paving mixture meeting all of the requirements contained in this specification. Specifically the plant shall provide proper aggregate gradation, asphalt-rubber binder content and mixing temperature.

6.2 MIXTURE SPREADING EQUIPMENT: Paving shall be accomplished with self-propelled, mechanical spreading and finishing equipment, pneumatic tire or tracked type, having a tamping bar or vibratory screed or strike-off assembly capable of distributing the material to not less than the full width of a traffic lane and to the depth needed to achieve the minimum compacted thickness or finished grade as required. The screed or strike-off assembly shall be equipped with a heating unit that maintains the temperature needed to prevent tearing of the paving mixture during spreading. Pavers that leave ridges, indentations or other marks in the surface that cannot be eliminated by rolling or prevented by adjustment in operation of the equipment shall not be used.

6.3 HAULING EQUIPMENT: Trucks for hauling the paving mixture shall be end, belly or bottom gate dump or moving bottom (horizontal discharge) type, and compatible with the spreading equipment. If an end dump unit is used, the bed shall not push down on the paver receiving hopper when fully raised or have too short a bed which results in mixture spillage in front of the paver.

The trucks shall be equipped, when ordered by the Engineer, with a canvas or similar covering so as to prevent excessive heat loss during cooler weather or as a result of long hauling distances.

6.4 COMPACTION EQUIPMENT: Rollers shall be self-propelled, 2-axle (tandem) steel-wheel type and shall have a minimum weight of 8 tons. All rollers shall be equipped with pads and a watering system to prevent sticking of the paving mixture to the steel wheels (drums). Vibratory rollers shall be used for breakdown passes on gap-graded mixes except when this causes excessive aggregate fracturing and the Engineer directs otherwise. The contractor shall furnish a minimum of two of the rollers as described above. Pneumatic-tired rollers shall not be used, due to the increased adhesiveness of the asphalt-rubber binder.

6.5 BLOTTER SPREADING EQUIPMENT: Blotter shall be spread using hopper or whirl type tailgate spreaders.

7. CONSTRUCTION PROCEDURES

7.1 GENERAL: Potholes and other areas of pavement failure and major depressions in the existing pavement surface shall be repaired by patching with asphalt concrete.

Cracks greater in width than 1/4 inch shall be repaired with an appropriate filler or sealant.

Immediately prior to application of a tack coat, the surface shall be thoroughly cleaned by sweeping.

7.2 TACK COAT: The type, grade or designation, and the rate of application for the specific usage will be specified by the Engineer.

7.3 ASPHALT-RUBBER PRODUCTION RECORDS: The asphalt-rubber supplier shall maintain records indicating for each batch of asphalt-rubber binder produced the quantity of asphalt cement in gallons and pounds, the temperature of the asphalt cement, the amour . of anti-strip or other additives, if used, in gallons and/or pounds, and the quantity of CRM in pounds. This information shall be provided to the Engineer on a daily basis.

7.4 ASPHALT-RUBBER/AGGREGATE MIXTURE PREPARATION: The asphalt-rubber binder shall be at a temperature of 300°F to 375°F when pumped and metered into the mixing plant.

The aggregate shall be dried and heated to provide a paving mixture immediately after mixing with a temperature not exceeding 325°F and a moisture content not exceeding 1.0 percent by weight of mixture.

The mixing operation shall be sufficient to achieve a satisfactory mixture with 100% coated particles as determined by AASHTO T 195 or ASTM D 2489.

If the mixture is discharged from the mixer into a hot-mix surge or storage bin, the bin shall be operated so that segregation of the mixture will be minimized.

7.5 HAULING OF ASPHALT-RUBBER/AGGREGATE MIXTURE: Truck beds shall be clean of materials such as dirt, mud and aggregates. Just prior to loading of the mixture, the truck bed shall be sprayed with a light application of a soapy solution or a silicone emulsion to reduce sticking of the mixture to the truck bed. Oiling of truck beds with kerosene or diesel fuel will not be permitted due to adverse effects on the binder.

7.6 SPREADING OF ASPHALT-RUBBER/AGGREGATE MIXTURE: The mixture shall be placed and finished by means of paving equipment as required by Section 6.2 except under certain conditions or at certain locations where the Engineer determines the use of self-propelled pavers impractical. The temperature of the mixture immediately behind the paver shall be a minimum of ___" °F.

The paving equipment shall place the mixture without segregation or tearing within the specified tolerances true to the line, grade and crown indicated on the plans. In order to achieve a continuous spreading operat the speed of the paver shall be coordinated with the production of the mixing plant.

The width of each pass of the paver shall be limited to the maximum width of the heated screed or strike assembly and side augers. The screed may be extended, at the discretion of the Engineer, beyond the en the auger for short distances where irregularities in the pavement width occur.

The mixture shall not be placed on any wet surface or when weather conditions will otherwise prevent pro handling or finishing. The recommended minimum atmospheric temperature for placement of thin (1-inch thi overlays is 50°F and rising.

7.7 COMPACTION OF ASPHALT-RUBBER/AGGREGATE MIXTURE: The mixture shall be rolled by means the compaction equipment as required in Section 6.4. A minimum of two rollers shall be used for mixtı compaction unless otherwise directed by the Engineer.

Initial or breakdown compaction shall commence immediately after mixture spreading and shall continue until t minimum required density [1] is obtained, unless otherwise directed by the Engineer. All rolling shall accomplished without excessive aggregate fracturing or mixture shoving.

7.8 APPLICATION OF BLOTTER MATERIALS: The application of blotter material (usually 1 to 2 pounds p square yard) meeting the requirements of Section 4.3 may be required on a warm mat before opening to traff The use, rate and locations for blotter material shall be designated by the Engineer. Any blotter material shall uniformly applied using equipment specified in Section 6.5. The contractor shall be responsible for removi excess blotter material within 24 hours after application.

7.9 TRAFFIC CONTROL: Traffic shall be directed through the project with such signs, barricades, device flagmen, and pilot vehicles as may be necessary to provide the maximum safety for the public and the workm with minimum interruption of the work and to protect the mat from damage until sufficiently cooled or cover with blotter to carry traffic.

8. METHOD OF MEASUREMENT AND BASIS OF PAYMENT

8.1 ASPHALT-RUBBER BINDER: The asphalt-rubber binder shall be measured and paid for per ton of binder the mixture under Asphalt-Rubber Binder which includes asphalt cement, crumb rubber modifier (CRM), and ar additives.

8.2 ANTI-STRIP: Anti-strip material will be measured and paid for: per gallon for liquid anti-strip; or per ton fc hydrated lime or portland cement.

8.3 ASPHALT-RUBBER CONCRETE: The asphalt-rubber/aggregate mixture shall be measured and paid for pe ton in-place under Asphalt-Rubber Concrete which includes the mineral aggregate as specified, asphalt-rubbe concrete mixture preparation, hauling, spreading and compaction as specified.

8.4 BLOTTER MATERIAL: The blotter material will be measured and paid for per ton in-place under Blotte Material, as specified.

8.5 TACK COAT: The tack coat will be measured and paid for per ton in-place under Asphalt for Tack Coat, a specified.

8.6 PATCHING: Any pavement patching as specified will be measured and paid for per square yard unde Pavement Repair (patching).

8.7 CRACK SEALING: Any crack sealing as specified will be measured and paid for per linear foot unde Pavement Repair (crack sealing).

8.8 TRAFFIC CONTROL: The traffic control will be a lump sum item and paid for under Traffic Control, as specified.

NOTES TO ENGINEER

A. Specify that either an open-graded or gap-graded asphalt-rubber concrete pavement is to be constructed. The open and gap-graded mixes can (and should) be produced at higher binder contents than conventional dense-graded mixes, which increases their durability and flexibility (resistance to cracking). The increased stiffness of the asphalt-rubber binder at high temperatures and the improved stone-to-stone contact of these mixes provides increased resistance to rutting.

B. The asphalt-rubber binder is typically designed for three nominal climate ranges, hot, moderate, and cold, as shown in Table 1. The first blank in Section 3 should specify the type of asphalt-rubber to be used (Hot, Moderate, or Cold)

C. It is not necessary to specify the grade of asphalt cement to be used in preparing the asphalt-rubber binder. The asphalt-rubber supplier should be allowed select the grade of asphalt cement that when blended with the CRM will meet the properties specified in Table 1.

D. For open or gap-graded mixes, either Grade A or Grade B is acceptable.

E. *Proper selection of mineral aggregate is very important for production of asphalt-rubber concrete paving mixtures.* In addition to the general descriptive requirements contained in Section 4, other parameters are also used in this specification for identifying aggregates which are appropriate for specific mixtures and traffic conditions. Limits for these parameters follow in Table 3.

TABLE 3
SUGGESTED GRADATION SPECIFICATION
FOR
OPEN AND GAP-GRADED ASPHALT-RUBBER CONCRETE

Mix Type	Open-Graded		Gap-Graded		
Sieve Size	3/8"	1/2"	3/8"	1/2"	3/4"
1"	100	100	100	100	100
3/4"	100	100	100	100	90 - 100
1/2"	100	95-100	100	90-100	65 - 85
3/8"	85-100	75-95	78-92	70-90	50 - 70
#4	25-55	20-45	28-42	24-42	22 - 42
#8	5-15	5-15	15-25	15-25	15 - 25
#30	0-10	0-10	5-15	5-15	5 - 15
#200	0-5	0-5	3-7	3-7	3 - 7

The limits contained in Table 3 are intended to be a guide for selection of appropriate aggregates. These limits may be modified for use in areas where aggregates meeting these requirements cannot be produced at a reasonable cost. The use of a standard gradation from a state highway department, city or county that generally follows these guidelines may be acceptable.

Aggregate quality is very important to performance of any hot mix, including those produced with asphalt-rubb binders. The increased stone-to-stone contact of the open and gap-graded mixes requires the use of hard crush stone or gravel. The following presents recommended physical requirements for aggregates to be used asphalt-rubber concrete mixes.

Table 4
Recommended Physical Requirements for Aggregates

Fractured Faces (Retained #8)	2-fractured faces 1-fractured face	85% minimum 90% minimum
Abrasion Loss (AASHTO T 96)	100 revolutions 500 revolutions	8% maximum 35% maximum
Sand Equivalent (AASHTO T 176)		55 minimum
Clay Lumps & Friable Particle in Aggregate (ASTM C 142)		1.0% maximum

If an agency normally uses other tests not shown here which eliminate poor quality aggregates, any such tests an appropriate limits should also be included in the specification.

F. Select who will perform the mix design. If no experienced independent laboratory or other source is available, we recommend that the asphalt-rubber supplier either perform the mix design or at least be consulted regarding appropriate procedures and evaluation criteria.

G. Gap-graded asphalt-rubber mixes can be designed using modified Marshall or Hveem procedures, but evaluation criteria differ significantly from those for standard asphalt concrete mixes. In general, asphalt-rubber hot mixes should be designed at greater binder contents than standard asphalt concrete mixes.

Recommended Marshall and Hveem mixture properties for the respective mix types are as follows:

Mixture Property	Gap-Graded	Open-Graded
Marshall Stability	Report	N/A
Hveem Stabilometer	Report	N/A
Marshall Flow	Report	N/A
Effective Voids	3 to 6%	See Note [1]
VMA	Minimum 18%	Minimum 22%
Retained Tensile Strength (ASTM D 4867, with freeze cycle recommended)	Minimum 60%	N/A
Asphalt-Rubber Binder Content, by Wt. of Total Mix	N/A	See Note [2]

[1] Effective voids of laboratory compacted open-graded mixes should be determined using paraffin coated specimens (ASTM D 1188).
[2] Binder contents for Open-Graded mixes are generally between 8.5 and 11.0 percent

H. Recommended mixture spread temperature are:

Open-graded - minimum 250°F
Gap-graded - minimum 270°F

I. For gap-graded mixes the recommended compaction is at least 95% of the laboratory density obtained from field samples of the mix, or a minimum of 92% of theoretical maximum density obtained from field samples. For open-graded mixes compaction is typically controlled by a method specification with a minimum number of coverages of rollers and/or establishing a rolling pattern using a test section. Requirements for sampling and testing of density should be incorporated into this section.